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Introduction

Freezing temperatures in the spring and fall of the year are important to many farmers and home gardeners. For most agricultural areas in southern Ontario, spring frosts in May and June and autumn frosts in September and October are the main concern. However, in northern areas of the province, temperatures can dip below the freezing point even during the months of July and August. Crops which are most affected by freezing temperatures include corn, soybeans, tobacco, potatoes, tomatoes, apples, strawberries, peaches, beans, cucumbers, pumpkins and other tender fruits and vegetables. The extent to which freezes damage crops in Ontario varies from year to year, depending on the location of occurrence and severity.

Although the terms "frost" and "freeze" sometimes take on somewhat different meanings, for the purpose of this Factsheet these terms are used interchangeably. Both define a condition that exists when the temperature of the air or of an object near the surface drops to the freezing point of water (0C) or lower.

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Advective Freeze

Freezes (or frosts) may be of the advective type, radiative type or a combination of both, depending on the weather conditions under which they occur. An advective freeze is caused by movement of cold air into the area (advection). This usually occurs after a cold front associated with a low pressure system moves through.

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Winds generally shift counter clockwise towards the northwest or north, bringing down cold arctic air. Advective freezes are usually widespread and may be accompanied by moderately strong winds. Freezing temperatures may persist during the day as well as at night. These freezes can occur under cloudy conditions, although there is usually some clearing due to the cooler, drier air mass. Because advective freezes are usually severe, farmers can do little to prevent damage to crops that are still in the field at the time they occur. However, freeze damage may be prevented by "passive" control methods that are used well in advance of the time the freeze happens, such as timely planting and harvesting, and proper crop selection for the area. Advective freezes are most common in early spring or late fall, and therefore mostly affect frost&SHY;sensitive crops which must be planted very early and/or harvested late in the season.

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Radiative Freeze

Radiative freezes occur only on nights with relatively clear skies and calm winds. Under these conditions, heat energy is lost from the earth's (crop) surface by longwave infrared (invisible) radiation. Under cloudy skies, this radiation is absorbed by clouds and partly re&SHY;radiated back to earth. Since clouds prevent most of the cooling by radiant heat loss, these freezes do not occur under cloudy conditions.

Radiative freezes may be expected when an area is under the influence of a relatively cool dry air mass associated with a high pressure weather system. During daytime the temperature may be well above freezing. However, rapid cooling after sunset causes the thermometer to dip to below&SHY;freezing levels. Since radiative freezes depend on nighttime cooling, they may often occur during only a few hours in the early morning just before sunrise when temperatures are at their lowest and winds are calm.

Freeze damage to crops can sometimes be prevented by using "active" methods such as covering plants or adding heat (see OMAFRA Factsheet, *Freeze Protection Methods for Crops*, Order No. 85-116).

Radiative freezes are of most significance in late spring and early autumn, but can also occur during summer in northern areas. Crop damage is usually localized, occurring on specific farms, fields or portions of fields because of temperature differences over short distances.

Most crop&SHY;damaging freezes that occur in Ontario are a combination of the advective and radiative type. A typical sequence of events is as follows: An advancing cold front associated with a low pressure system has moved trough the area. Winds have shifted to the northwest or north, bringing in cold dry arctic air. This is followed by a clear calm night which favours further cooling of the air mass, causing frost.

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Vertical Temperature Patterns During Freezes

Advective and radiative freezes produce very different temperature patterns, both in the horizontal and vertical directions (Figures 1 and 2). In practise, variations from these ideal patterns can exist.

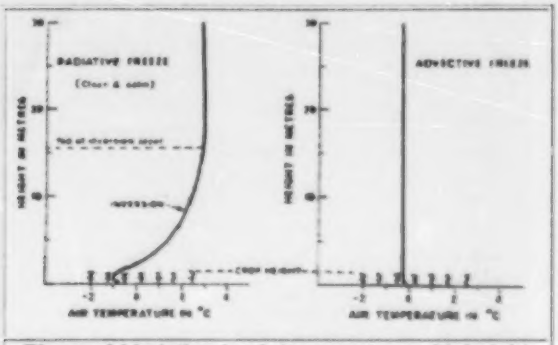

Figure 1 Variation in air temperature with height above ground during radiative and advective freezes

During radiative freezes, air temperatures in a standard thermometer or Stevenson screen about 1.3 meters (m) above ground may be 3 or 4°C or more colder than the air at a height of, say, 20 m because cooling takes place mainly from the surface by radiative heat loss (Figure 1). This process creates a situation known as a temperature "inversion", since during daytime the temperature usually decreases with height. During inversions, the air is very stable, and very little mixing occurs between the cooler air at the surface and the warmer air aloft. This is because the cold air near the surface is heavier than the warmer air above it. Strong sudden gusts of wind can break up the inversion layer and cause mixing of warm and cold air layers. This can sometimes cause temperatures to rise several degrees very quickly during the night. Under 'ideal' frost nights the winds remain calm and skies stay clear until morning, so that the inversion is not broken up until the sun rises and begins heating the air at the surface.

Large differences in the temperature of the air at the height of a standard thermometer screen and the air just above the ground are also common during a radiative freeze. In addition, if plant parts or other surfaces are exposed to the clear sky at night, the radiant heat loss from these surfaces causes their temperature to drop as much as 2 or 3°C below that of nearby air layers. For example, on clear, calm nights, it is not unusual for an exposed thermometer located just above a short grass surface to read 5 or 6°C lower than a thermometer in the screen located 1.3 m above ground. Therefore, ground frost can occur even when the "official" temperature recorded in the screen at the nearest weather station does not drop below freezing. As a "rule of thumb" in forecasting, a frost warning is usually issued for low lying areas if the minimum air temperature is expected to drop to around 5°C or less under clear calm weather conditions.

Vertical temperature patterns near the surface may be influenced by soil conditions and surface cover. For example, the air just above a bare soil surface will generally be warmer than over a short grass surface because the bare soil releases more heat during the night, while the grass surface acts as an insulator. However, soil that is very loose and dry at the surface also behaves like an insulator. Materials such as straw or other mulches, dry peat surfaces, etc. act as insulators which result in lower temperatures near ground level and larger temperature differences between the weather screen and ground level during a radiative freeze. In sloping terrain with good air drainage, the movement of air down the slopes may result in smaller temperature differences between the weather screen height and ground level.

Since the temperature of plant parts and other surfaces exposed to the clear sky may drop several degrees below air temperature, dew and frost tend to form most quickly on these surfaces. Moisture that is in the air condenses as the air is cooled when in contact with these surfaces. Leaves or other plant parts located in the mid

to lower part of a crop canopy are often partly shielded from the clear sky by upper leaves. This shielding effect reduces the radiative heat loss from these plant parts and results in smaller differences in temperature between the leaf and the air next to it. This shielding thus provides a measure of protection against frost. A similar effect is clearly observed when farm vehicles are parked under a roof. The roof prevents radiant heat loss from the metal surfaces so that dew or frost is not likely to form on the vehicle surface during a clear calm night.

During advective freezes, temperatures at the crop surface and at, say, the 20 m height are usually very similar, as shown in Figure 1. This is because windy conditions usually result in quite a lot of mixing of the air layers at different heights. In addition, advective freezes may occur under cloudy conditions which reduce the radiative heat loss and result in less cooling at the surface.

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Horizontal Temperature Patterns During Freezes

The typical horizontal temperature patterns that form during radiative and advective freezes are shown in Figure 2. During radiative freezes, the air temperature may change rapidly over short distances in areas with sloping terrain. Frosts usually occur first in low-lying areas because the cold air near the surface is heavier than the warmer air aloft, and therefore tends to flow by gravity into the hollows. This produces the commonly observed 'frost pocket' effect. Temperature differences will usually be greatest in areas with the largest changes in elevation. However, even a very gradual slope (for example, a 10 m drop over a distance of 1 km) can produce temperature differences of several degrees (C) which can be significant for frost sensitive crops.

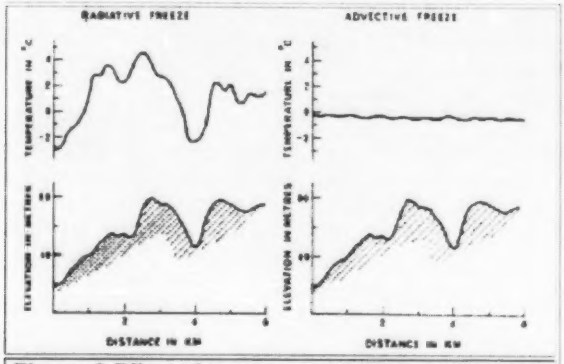

Figure 2 Effect of terrain on nighttime minimum air temperatures at 1.3 m above ground during radiative and advective freezes

The pattern shown in Figure 2 is for a relatively "ideal" situation. In some areas where the terrain pattern is very complex, the relation between elevation and minimum temperature may be more complicated. In addition, wind and cloud during the night can cause the normal temperature pattern to be disturbed.

The drainage of cold air down slopes into the hollows can sometimes be partly blocked by dense trees, road embankments or other obstructions, and cause pockets of cold air to form on the upward side (Figure 3). This effect can sometimes be reduced by thinning the trees to allow cold air to move through and provide better air 'drainage' .

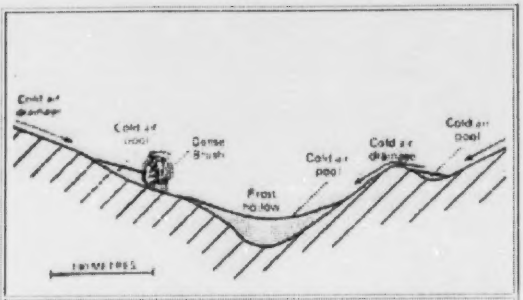

Figure 3 An example of cold air drainage patterns in sloping terrain

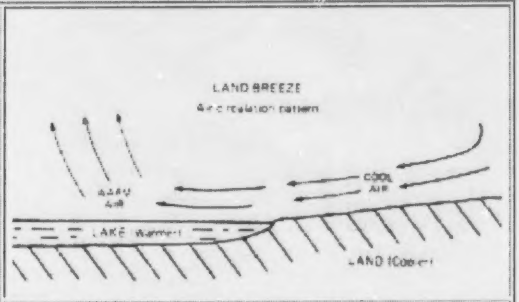

Figure 4 Typical land breeze circulation pattern near large water bodies

In areas with level topography, temperatures are usually fairly uniform during both radiative and advective freezes, although they may be affected by the nature of the soil and vegetation. In areas near large water bodies such as the Great Lakes, temperatures may be increased by "land breezes" which develop during the night. Land breezes form due to the fact that the air over land cools more quickly than that over water during radiative freezes. This results in a pressure difference which causes an air circulation pattern as shown in Figure 4. In addition to the mixing effect of land breezes, low&SHY;lying land near a large body of water is less prone to frost than areas of similar elevation further inland because cold air moving down slopes can move freely out over the water rather than being trapped in the hollows.

During freezes caused by advection of cold air, temperatures are usually quite uniform over fairly large areas. Changes in elevation in areas of hilly terrain such as shown in Figure 2 have little or no effect on the temperature under these conditions. In some advective freeze situations, however, exposed locations on hilltops have been known to freeze before fields located in hollows or sheltered by windbreaks. Although small elevation changes have almost no effect on temperature, larger changes of several hundred metres or more such as occur in mountainous areas can result in significant cooling of the air as it rises or warming as it descends. Large water bodies have a moderating effect on temperature of areas downwind during an advective freeze, particularly in autumn, when the water is considerably warmer than the air.

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Predicting Frost Occurrences

Since there are many factors that influence the minimum temperature, it is often difficult to predict exactly when frosts will occur in specific farm fields. Statistics from the nearest weather station can be useful to indicate the safe frost&SHY;free period in an area. However, weather stations often do not represent on&SHY;farm

conditions very well in areas where changing elevations or large water bodies influence nighttime temperatures. Weather forecasters can provide general guidance on the risk of frost, for example, in low&SHY;lying areas, but do not make adjustments for specific on&SHY;farm situations. Thus farmers frequently have to rely on local experience. One way of improving the prediction of frost is by making on&SHY;farm measurements of minimum temperature in specific crops or fields and comparing these to temperatures at weather stations in the area. These results can be used to estimate spring and fall frost probabilities on the farm and to make adjustments to minimum temperature forecasts. However, for best results, such measurements and interpretations should be made with the guidance of an experienced agricultural climatologist or meteorologist.

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